MONOTONIC AND CYCLIC BEHAVIORS OF ENERGY-DISSIPATING THREADED MECHANICAL SPLICES

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ABSTRACT :
In this study, energy-dissipating threaded mechanical splices are developed. The spice is composed of a hollow steel coupler threaded throughout its length and two reinforcing bars with threads at their ends. The coupler is designed to fail with sufficient energy dissipation. The amount of energy dissipation at the coupler is controlled by the coupler thickness and the gap length which are invested in this study by a series of monotonic and cyclic loading tests. The couplers are made from SS400 steel and the threaded bars are 20-mm-diameter steel bars with the nominal yield strength of 500 MPa. The coupler thickness and the coupler gap length are varied. In compression, the mechanical splices exhibit higher compressive strength with more post-buckling resistance than the plain control bar by about 12%. In addition, the energy dissipation of the splice is 5 times the plain bar. In tension, the maximum load is close to the capacity of the coupler as intended. The energy dissipation of the mechanical splices increases when the coupler gap length increases. However, the ductility of plain bars is approximately 5 times the ductility of the splices in tension. The spices with different gap lengths are subjected to cyclic loading. It is important to note that the deformation in tension is limited by the tension rupture of a coupler. For a column with failure controlled by buckling of reinforcing bars, the energy dissipating threaded mechanical splice can improve the post-yielding behavior with less difficulty in repair.

KEYWORDS:
Energy dissipation, reinforced-concrete, mechanical splice, loading test

1. INTRODUCTION

Precast concrete structures have the advantages of high quality control, and construction speed. The inadequate seismic response of pre-cast structures is a major concern and the subject of research efforts. The development of proper connectors between the pre-cast members is important for application in seismic regions (Hieber et al., 2005 and Fouad et al., 2006). Such connections must exhibit sufficient strength, ductility, and energy dissipation capacity. Mechanical splices are cost-effective devices that are commonly attached to structural members subjected to gravity loads.

In this study, energy-dissipating threaded mechanical splices are developed. The spice is composed of a hollow steel coupler threaded throughout its length and two reinforcing bars with threads at their ends. A lock nut may be used so that two reinforcing bars are not rotated relative to each others when assembling. The coupler has a gap between the ends of reinforcing bars, allowing deformation and energy dissipation to take place. The coupler is designed to fail with sufficient energy dissipation. Then, the repair at a connection after an earthquake event will be simplified by replacing couplers. The amount of energy dissipation at the coupler is controlled by the coupler thickness and the gap length which are invested in this study by a series of monotonic and cyclic loading tests.

2. ENERGY-DISSIPATING THREADED MECHANICAL SPLICE

Basically, mechanical splices are used to connect bars to transfer tension or compression forces. Hence, couplers in mechanical splice systems are designed to have the tension strength larger than that of reinforcing bars or at least 1.25 times yielding strength of reinforcing bars (UBC, 1997). This will ensure sufficient strength in splices so that yielding and failure will occur at bars. In this research, the couplers with adequate ductility were designed to have the resistance less than that of the reinforcing bars. So when earthquake occurs, the coupler will yield before the bars. The coupler will act as a fuse in a column to absorb energy. This may be used in the construction of precast structures especially in precast columns. Figure 1 shows the configuration of the mechanical splices used in this study.

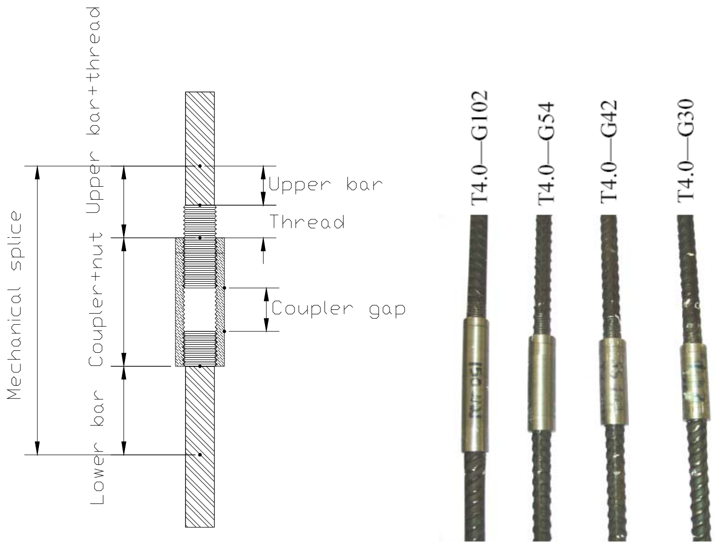


Figure 1 Assembly of mechanical splice used in the study

The threaded bars used for this study are 20mm-diameter reinforcing bars with a SD50 grade. The stress-strain relation of the bar from the tensile test is shown in Figure 2. The bar has yield and ultimate strengths of 553 MPa and 663 MPa, respectively. The modulus of elasticity is equal to 206 MPa. The percentage of elongation at failure is 16%. The threaded couplers used in this study are produced from the SS400 steel. The coupler specimens are designed to have various thicknesses and lengths with the threaded size of M24×3.0. The stress-strain relation of the SS400 steel is shown in Figure 3. For the SS400 steel, the yield strength is 445 MPa and the ultimate strength is 535 MPa. The percentage of elongation is 12.7 % at failure. The SS400 steel is used because there is no strain hardening in the material. Hence, the failure of the splice can be controlled to occur in the coupler which is made of the SS400 steel.

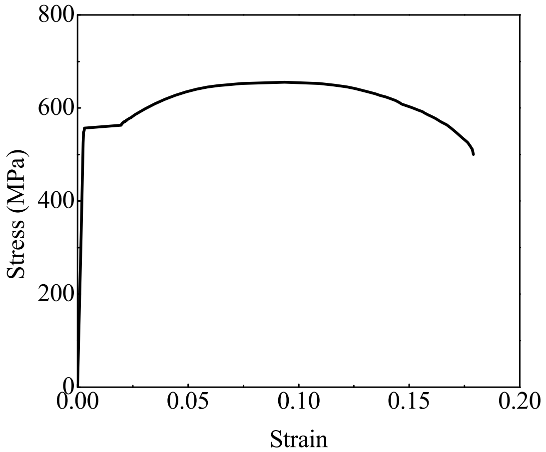


Figure 2 Stress-strain relation of the reinforcing bar

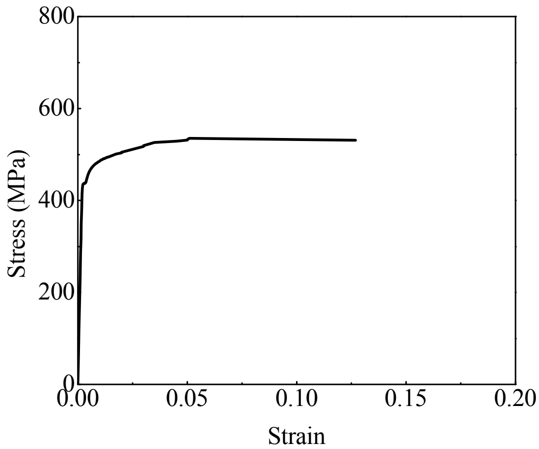


Figure 3 Stress-strain relation of the SS400 steel

3. PARAMETERS AND TEST SETUP

To control the failure of the splice, the thickness and gap size of the coupler are varied. The thickness controls the yielding force level while the length or the gap size controls the deformation capability of the coupler. The coupler thicknesses are equal to 3.0mm, 3.5mm, 4mm, 4.5mm and gap lengths are equal to 30, 42, 54 and 102 mm. Table 1 shows the parameters for tensile test. Table 2 lists the specimen names. T and G are represented for the coupler thickness and gap length, respectively. Table 3 shows the parameters for compressive test and cyclic test.

Table 1 Cases for monotonic tensile test

Gap (mm)	Thickness (mm)				Coupler Length (mm)
	3	3.5	4	4.5	
30	√	√	√	√	78
42		√	√		90
54		√	√		102
102		√	√		150

Table 2 Specimen name

Specimen Name	Properties	
	Thickness (mm)	Gap (mm)
Control Bar	-	-
T3.0-G30	3.0	30
T3.5-G30	3.5	30
T3.5-G42	3.5	42
T3.5-G54	3.5	54
T3.5-G102	3.5	102
T4.0-G30	4.0	30
T4.0-G42	4.0	42
T4.0-G54	4.0	54
T4.0-G102	4.0	102
T4.5-G30	4.5	30

Table 3 Cases for monotonic compressive test and cyclic test

Gap (mm)	Thickness (mm)				Coupler Length (mm)
	3	3.5	4	4.5	
30			√		78
42			√		90
54			√		102
102			√		150

The test setup is shown in Figure 4. The gage length is 200 mm. The potentiometer is used to measure the deformation. The larger deformation is measured by a digital vernier caliper. Tests are conducted to ascertain that the setup gives correct measurement of the modulus of elasticity. The test is done under the displacement control mode with the cross head speed of about 0.50 mm/min which is within the range specified in ASTM standard E 8M-04 for tension testing of metallic materials.

In the cyclic loading test, specimens are subjected to tension and compression at $\pm 3\delta_{cy}$, $\pm 6\delta_{cy}$, $\pm 9\delta_{cy}$, and $\pm 12\delta_{cy}$ for two cycles per a specified maximum deformation where δ_{cy} is the yielding deformation. The value of deformation at yielding is approximately 0.60 mm obtained from the tensile test of the specimen T4.0-G102. Figure 5 shows the loading scheme.

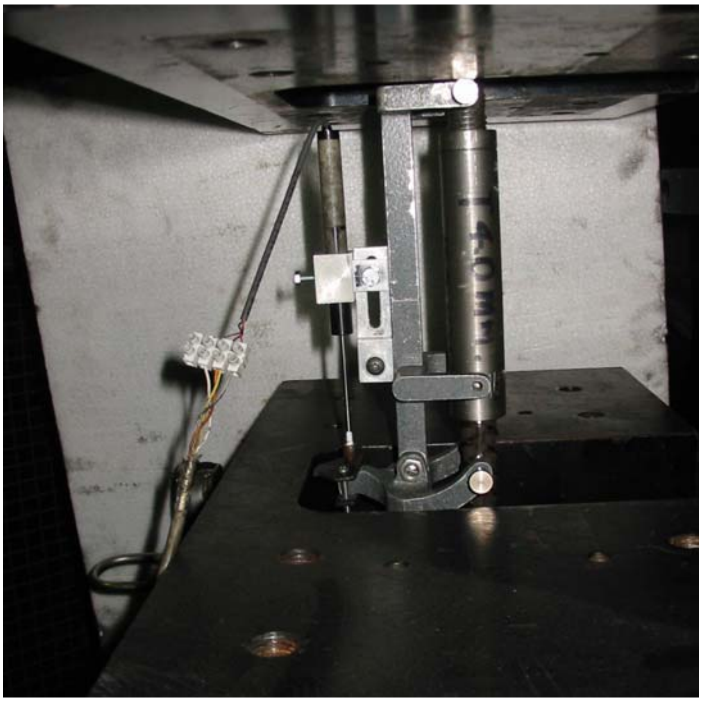


Figure 4 Test set-up

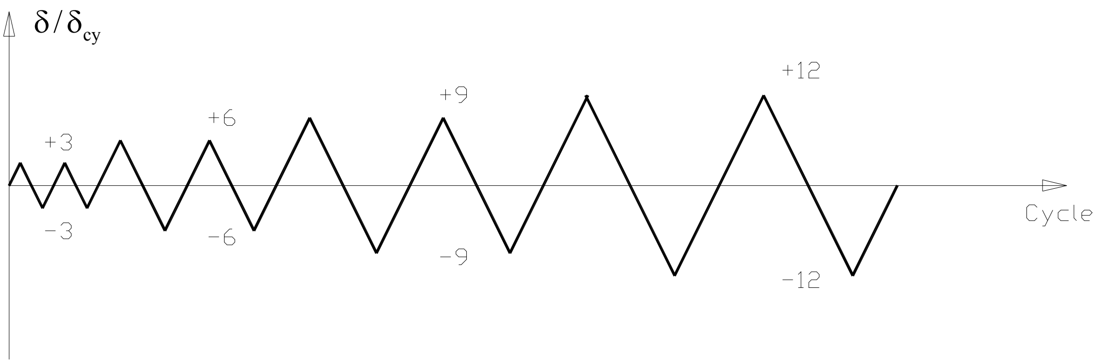


Figure 5 loading scheme of cyclic loading test

4. TEST RESULTS AND DISCUSSIONS

4.1 Monotonic Tensile Test

To find out the optimal parameters of the mechanical splice that causes failure at the coupler with the largest energy dissipation, the tensile behavior of the mechanical splice specimens with variation of thicknesses was investigated. Figure 6 shows load-deformation relations of the specimens with different coupler thicknesses. It is seen that as the thickness of the coupler increases, the load resistance of the splice increases. The maximum loads of the specimens T4.0-G30 and T4.5-G30 are close to that of the control bar. And the failure of the specimens occurs in the reinforcing bars. Figure 6 also indicates that an increase of the coupler thickness from 3.0 to 4.0 mm increases both resistance and deformation. Comparing with the control bar, the deformation of the splice is smaller. The effect of the gap length on the tensile behavior of the mechanical splice specimens was investigated. The results are shown in Figure 7 for a thickness of 3.5 mm. It can be observed that the elongation of splices increases when the coupler gap length increases. The maximum load is more or less the same because it is controlled by the thickness. It is important to note that the deformation in tension is limited by the tension rupture of a coupler. It can limit the application of the energy-dissipating splice in the case with the large level of tensile strain.

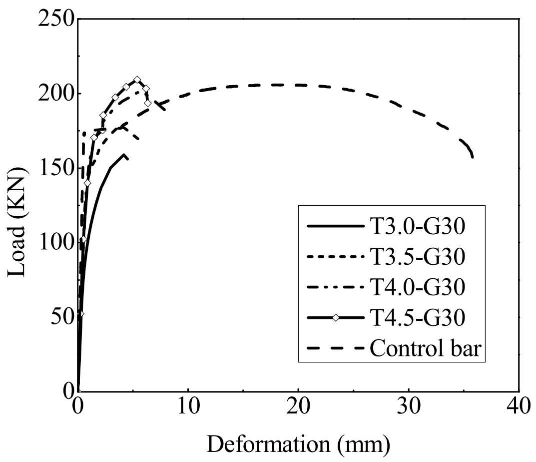


Figure 6 Load-deformation relations of control bar and mechanical splice specimens with different thicknesses

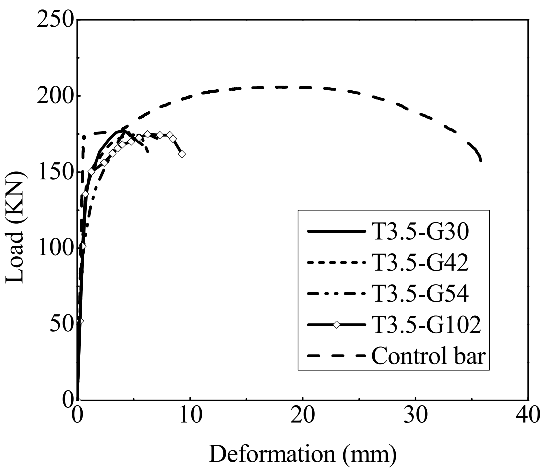


Figure 7 Load-deformation relations of control bar and mechanical splices with different gap lengths

4.2 Monotonic Compressive Test

The splices with a coupler thickness of 4.0 mm and various gap lengths are subjected to the monotonic compressive test. The load-deformation relations are shown in Figure 8. The maximum load of the control bar is 188 kN and the load drops suddenly after buckling. The energy dissipation of each specimen is evaluated at the deformation where the load dropped by 20% from the peak load. It is found that the energy dissipation of the splice with a coupler gap length of 102 mm is 4.88 times the energy dissipation of the control bar. The maximum load capacity of the splice is greater than that of the control bar by 11.8%.

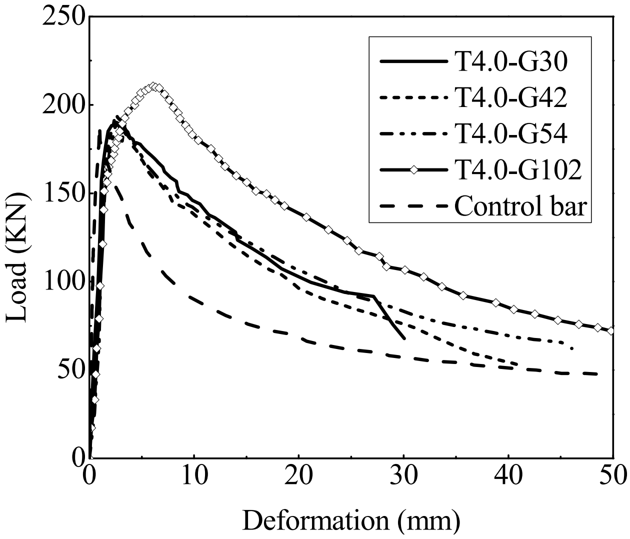


Figure 8 Load-deformation relations of control bar and mechanical splices under compressive test

4.3 Cyclic Loading Test

The cyclic loading test is conducted on a control bar using the loading scheme in Figure 5. The load-deformation relation is obtained as shown in Figure 9. The right side is in tension and the left side is in compression. The bar starts buckling at the deformation of about 1.5 mm and the load drops dramatically after buckling by about 40% of the peak load. The test stops when the load drops by 40% from the peak load. Figure 10 compares the hysteretic curves of the control bar and mechanical splice specimens with various gap lengths. It is obvious that the hysteretic loops in compression are stable in the compression side for the couple with the larger gap length.

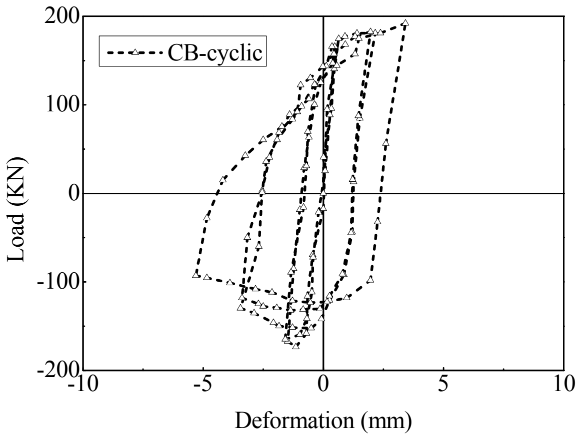
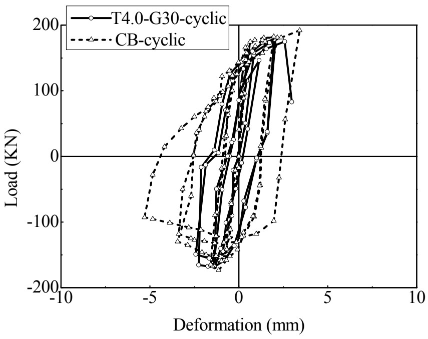
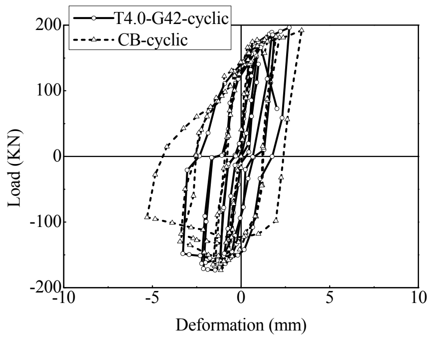


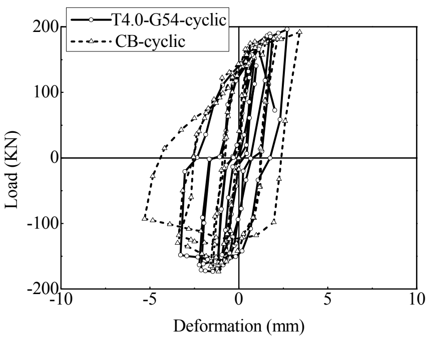
Figure 9 Load-deformation curve of the control bar



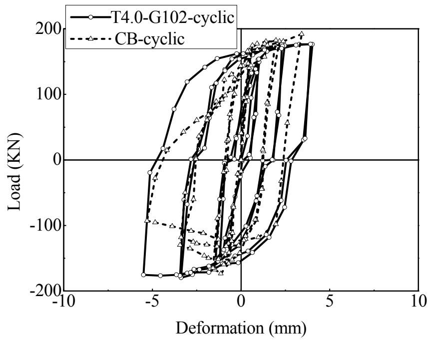
(a) Specimen T4.0-G30



(b) Specimen T4.0-G42



(c) Specimen T4.0-G54



(d) T4.0-G102-cyclic

Figure 10 Comparison of load-deformation curves of specimens under cyclic loading

5. CONCLUSIONS

In this research, tensile, compressive and cyclic behaviors of the developed threaded mechanical splices are investigated. Different parameters in terms of coupler thicknesses and gap lengths are considered. From a series of tests, the following conclusions can be drawn:

1. The load resistance of the mechanical splice is controlled by the coupler thickness while its ductility is controlled by the coupler gap lengths. In monotonic tension, the plain bar is more ductile than the mechanical splice. It is important to note that the deformation in tension is limited by the tension rupture of a coupler. It can limit the application of the energy-dissipating splice in the case with the large level of tensile strain.

2. The splices exhibit higher resistance in compression after buckling. The maximum load capacity of the splice with the largest coupler gap length is greater than the plain bar by 11.8%. At the displacement where the load drops by 20% from the peak load, the energy dissipation of the splices is about 2.4-4.9 times the energy dissipation of the plain bar. It is obvious that the buckling behavior of the bar could be improved by using the mechanical splice.

3. The energy dissipation of the mechanical splice in the cyclic test increases as the gap length increases. It is attributed to the improved compression behavior of the splice.

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